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RELIABILITY RESPONSIVENESS IN TECHNICAL PROPOSALS

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ABSTRACT

Technical proposals for military electronic systems, projects and equipments are now critically reviewed by Air Force Evaluation Boards for design-for-reliability. Reliability is a major design factor that must be considered in the initial system planning, during the design and development phase, and throughout the manufacture, site installation and checkout, and test cycle. Prospective contractors are required to clearly demonstrate in their proposals the the proposed configuration will meet the specified military reliability requirements. This report discusses and details those factors which must be developed by prospective contractors to assure responsiveness to the reliability/quality aspects. Although the emphasis is on electronic systems and equipments, the basic precepts described are readily adaptable to all Air Force systems and equipments.

REVIEW AND APPROVAL

This technical report has been reviewed and is approved.

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SECTION 1

INTRODUCTION

Design of reliable electrical and electronic circuits and equipment has shifted from corrective philosophy and techniques to preventive philosophy and techniques. In the past, design for mission performance came first; reliability design was a modification kit produced only after field failures made a more reliable design imperative. Today the emphasis is on increased inherent reliability in the early and initial design stage. This emphasis can be readily understood when one considers that current electronic systems can have part populations totaling upwards to 450,000,000. Compare this with World War II Radars, complex in their time, that rarely exceeded 45,000 parts. Or further, compare this to missile systems, whose piece parts are in the order of 50,000.

Many of today's ground electronic systems are one-of-a-kind, and production in quantities is the exception rather than the rule. In some instances, major items such as radars and communication equipments, are procured in quantities; however, a "second chance" to redesign an electronic system for improved reliability is rare. The first model fabricated is usually the one that is installed in the field; it almost always becomes an operational item of the military inventory. On those rare occasions where an additional model(s) of an electronic system is procured, the second resembles the first in performance parameters only. There is generally a dramatic physical and electrical difference between the first and subsequent models of electronic systems, largely due to advances in circuit designs, components, and solid state techniques, that occurred after the first model was designed.

This report concentrates on "ground" electronic systems; however, the approach to reliability requirements for other types of Air Force electronic systems and equipments could be similiar. The scope, depth and extent of a reliability program varies with, and must be tailored to, the specific procurement situation.

SECTION II

BACKGROUND

Basic Air Force Systems Command Approach and Policies:

The increased importance of Reliability, particularly in the pre-contract and contract negotiation stages, is emphasized in the revised AFSCR 80-1, "Reliability Program for Systems, Subsystems, and Equipments." This regulation can be summarized in terms of its effect on Technical Proposals as follows:

a. "Quantitative reliability requirements will be stated in specific numerical terms in appropriate contractual documents and systems specifications and will include among other things, the confidence levels to which the specified probabilities will be demonstrated."

b. "Contracts for systems, subsystems, and equipment will include a requirement for a comprehensive and organized contractor reliability program that extends through subcontractor and vendor levels."

c. "Integrated test plans to investigate causes, effects, modes of failures, and to demonstrate achieved reliability will be developed and incorporated in contractual documents."

d. "New programs will include adequate funds for reliability effort in design proposals and initial program funding."

e. "Proposals for increasing reliability effort and funds during a program will be screened to assure that the effort is over and above that already required. Decisions to accept or reject such proposals will be based on their effect on spares, maintenance workload, and operating costs."

Reliability and the System Project Offices

AFSC Regulation 80-1 requires System and Project Office to have the necessary technical talent available to monitor and assure the reliability aspects of system and equipment contracts. At this point in time, two years since this regulation was issued, there has been a dramatic change in Air Force System and Project Offices concerning Reliability.

AFSCR 80-1A initiated the following important changes:

a. Each AFSC Division is now required to have an active, professional Reliability Staff. This Staff insures that all Development Plans, System Package Programs, Specifications, Work Statements, Purchase Request Packages, etc., contain reliability requirements, as pertinent. Further, the Division Staffs review overall progress and compliance to

reliability.

b. Equally important, the individual System and Project Offices must have active, qualified Reliability Monitors, on a full-time basis.

Perhaps the most interesting event, conceived and initiated by the Hq AFSC Reliability Staff, was a program established by the Air Force Institute of Technology leading to a Masters Degree in Reliability Engineering. The candidates for this program are carefully chosen from highly qualified engineering Air Force officers and civilians. Upon completion, the graduates are assigned to System Project Offices as full-time Reliability Monitors. The System and Project Offices are thus being staffed with qualified, competent, professional reliability engineers; engineers who can competently challenge as well as evaluate contractor's reliability efforts. In some respects, academically speaking, the Air Force is acquiring a higher level of reliability talent than is generally available to industry. It is predicted that both industry and the Air Force will benefit from the Masters Program in Reliability.

Reliability - A Technical Evaluation Factor

The majority of Research, Development, Service Test, and Production procurements require that Reliability be evaluated as one of the major technical factors during the source selection and contract negotiation phase.

Most of today's technical proposal evaluations assign a percentage or weight factor to the adequacy of the Reliability approach; therefore, it is possible to gain or lose a number of points, depending on the acceptability of the submitted data. It is not advisable to quote a weight-norm generally assigned to reliability as it varies for technical proposals. Reliability may be "weighted" from two to twenty per cent, depending on the procurement situation, the type of equipment being procured, the intended operational use, etc.

Reliability scoring includes "design for maintainability", "simplicity of hardware/equipment design", and the "compatibility of the quality control program." Reliability, therefore, is one of the primary factors of the proposal evaluation criteria. A technical Proposal with an unsatisfactory reliability content could readily render the entire proposal unacceptable.

Technical Proposal Evaluation Boards

The cost of preparing a proposal, particularly those prepared in response to an official Request for Proposal is important. Many thousands of dollars, and sometimes tens of thousands, are expended in the development of a proposal. Therefore, proposals should be more productive, to both industry and the military.

The Air Force evaluates proposals with boards consisting of qualified professional engineers and technical personnel. Virtually

every Board has a voting reliability engineer, whose prime mission is to determine if the proposal has or has not met the reliability requirements. This same individual is frequently associated with the subsequent reliability activities during the life of the contract.

One of the responsibilities of the Evaluation Boards, not generally known, is to determine if certain portions of proposals not selected are of interest from a technique aspect. The reliability representative, for example, may discover a new or unusual approach to a current reliability problem that might be of interest to another program or project, In this situation, the proposer would be encouraged to bid separately for just that portion of the proposal that is of interest, or, the company would be encouraged to submit a separate proposal, which would then be treated on a sole-source basis. In this area particularly, there is a wide use of not-for-profit organizations in the evaluation process.

Not-for-profit organizations are used in the technical direction and overall general systems engineering of ground electronic projects and programs. The not-for-profits are also now being utilized as advisors to Evaluation Boards. They participate in the evaluation of all portions of the proposal except the cost, which is never made available to them.

Evaluation Boards today are a direct answer to industry's concern, that when good technical proposals have been prepared by industry, fully qualified Air Force technical personnel be utilized to evaluate these proposals.

New Air Force System Life Cycle

The new Air Force Systems Command Manual AFSCM 375-4, "System Program Management Manual", describes the activities and events that all new Air Force systems will be required to establish and to be subject to during the life cycle of the system. Briefly, the new system life cycle is summarized in Figure No. 1 (page 6).

The following are the reliability events and activities that occur:

a. Conceptual Phase. The primary objective during the Conceptual Phase is to evolve and delineate realistic Reliability objectives that will satisfy the operational mission. This is the first opportunity to identify the features which affect the reliability characteristics. A study and investigation is made of the reliability aspects, and the implications of trade-offs between reliability and other constraints. Realistic reliability goals are fully evolved.

b. Definition Phase. Detailed quantitative reliability requirements are established during this Phase and are integrated in the detailed System Design Specification, which is the primary product of the Definition Phase. Reliability requirements are allocated to lower functional levels, and the impact on maintenance and other associated functions defined. In essence, a preliminary Reliability Program Plan is established at this point in time.

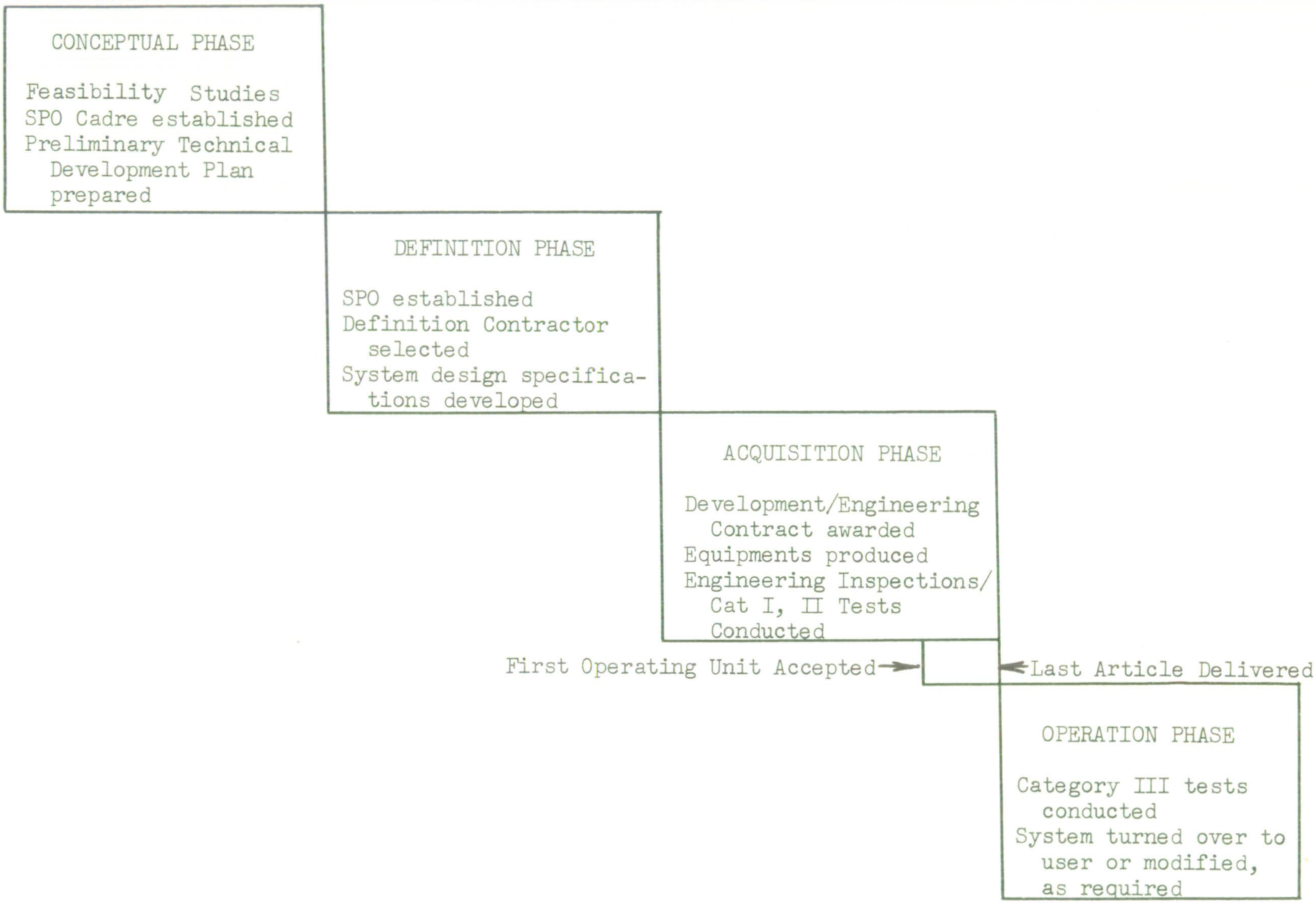

Figure 1. New Air Force System Life Cycle

c. Acquisition Phase. During this phase the contractor implements the reliability objectives, and the reliability program which was detailed and defined during the Definition Phase. The contractor also updates and revises the Reliability Program as necessary to meet the contractual quantitative reliability requirements. The engineering inspections and test programs are conducted at this time to determine the compliance of reliability with contractual requirements.

The principal significance to Reliability in the new System Life Cycle, is the opportunity to adequately insure that Reliability is initially considered, that realistic reliability requirements are established, and that reliability is in fact reflected in the delivered end items.

SECTION III

ANALYSIS OF RELIABILITY REQUIREMENTS

Approach

The first objective when analyzing the reliability requirements of a Request for Proposal (RFP) Package is to insure that the stated requirements and terminology are mutually understood, since eventually they must be agreed to by the customer and the potential contractor. However, in actual practice detailed reliability requirements are sometimes lacking, for the valid reason that the manner of accomplishment of the mission is not firm.

When Reliability has not been quantitatively specified by the Air Force, the reliability objectives and the reliability program consistent with product use must be established. All requirements should be related to operational figures of merit such as "percent up time," "mission success probability," "in-commission rates," or "average maintenance times." A contractor then can establish realistic levels derived from mathematical models of system and weapon effectiveness, and based on a study of the functions of specific system mission requirements. Overall system requirements are then "budgeted" for each system, subsystem, and major component. In general, the Air Force states reliability quantitatively when designs are firm. Conversely, reliability is stated qualitatively where only goals are known and have been given.

The work statement on reliability states the function the proposed equipment performs in operational use, and is further, an interpretation of reliability as it applies to broad performance parameters.

A prospective contractor must define this function and his interpretation of quantitative reliability as he understands it. Quite often the interpretation may vary depending on the configuration proposed. This will then clarify exactly what product reliability the prospective contractor is quoting.

Contractor proposals must establish reliability in proper perspective; that is, a proposal must show that the bidder is aware of the relationships between reliability, maintainability, logistics, human engineering, design simplicity, etc. The proposal must not isolate reliability as a separate science, but must show the relationship to, and trade-offs with, other functions and their design interactions. Often the best approach to a difficult reliability problem is a design ensuring high maintainability, particularly where the state-of-the-art in reliability will not in itself result in the reliability level required for a specific procurement. An approach that is particularly adaptable to electronic systems is that of "availability".

Availability

Availability is the proper balance and application of reliability and maintainability techniques. Two factors are necessary to calculate inherent availability; mean time before failure and mean time to restore service (in an excellent environment). The mean time before failure is a reliability factor, and the trouble clearing time is a maintainability factor. Low orders of reliability can frequently be greatly improved by a corresponding improvement in maintainability. Availability improves as the maintenance-action rate improves.

The military commander in the field is more confident knowing that there is a probability that his equipment will be available to perform a mission, than he is knowing that the Mean Time Between Failure (MTBF) is a high absolute number. Further, the military commander wants to be assured that he can initiate and successfully execute any particular mission, and this presupposes having the equipment available at the time of the mission.

In its basic form, the following relation is given to define availability:

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

The highest value A can have is unity, or 100 per cent. Availability is a ratio of system operating hours to the sum of system operating plus maintenance hours.

There are two methods to approach 100 per cent Availability of an electronic system. The system can be built (for a given mission time) to have such a high MTBF in relation to MTTR that Availability will be practically 100 per cent, or the ease of maintenance can be designed into the equipment to shorten the MTTR so much that this will also result in a very high Availability and permit the system to perform its mission, even with modest MTBF. The large number of serial parts of many electronic system prohibits the design for an order of reliability which will obtain the required order of high Availability through reliability techniques alone. The design for efficient and rapid maintainability is frequently the most practical way to supplement the design-for-reliability and achieve the required level of Availability, since attempts to incorporate more and more reliability generally skyrockets the cost of equipment.

It is interesting to note that the Martin Marietta Handbook, "Estimating Reliability," defines Availability as "Efficiency." A recent Navy paper delivered in Boston described Availability as "Dependability," and utilized reliability and maintainability as the prime components of the dependability equation.

In general, the submission of separate plans, one for main-

tainability and one for reliability, is discouraged. This is due to the unique operational requirements of electronic systems. These requirements involve a numerical expression for operational availability. The latter represents a simultaneous treatment of maintainability, expressed as a mean-down-time (MDT) statistic; and reliability, expressed as a mean-time-between-failure (MTBF) statistic.

Technical Proposals for electronic systems are therefore required to include one combined program plan. A plan which will describe the methods by which a contractor details the control of both the MDT and the MTBF characteristics of electronic systems, beginning with the design phase of a system program. This plan can be referred to as an Availability Program Plan. In substance then Availability gives equipment designers an area for reliability/maintainability trade-offs based on achieving a required availability at minimum design production, and maintenance costs.

Initial Prediction of Reliability

Technical Proposals for electronic systems must include a preliminary analysis of reliability requirements. The bidder is required to make a "first prediction" of reliability capability for the designs/equipments that he is proposing. The bidder must then discuss and compare the results of his "first prediction," with the desired reliability requirements. It is never sufficient for the contractor to merely state that he "will meet all required reliability requirements," or that he "will comply with all contractual requirements." It is important that all derived equations and mathematical assumptions are clearly stated, so that they may be verified by the members of the Technical Proposal Review Board. The proposer is required to make an estimate of the reliability which can be achieved during the course of the contract, and to provide data which will validate this estimate.

While developing the reliability estimation, preliminary quantitative numbers are developed by the bidder which will be based on existing or known failure rate data sources. It is necessary at this point to detail the failure rate data sources and to discuss the adequacy of the sources utilized. The prospective contractor must indicate the degree of confidence and/or experience that he has had, with the accuracy of the failure rate data sources that he utilized for his "first prediction."

A primary objective of early reliability prediction is identification of any possible reliability weaknesses in the proposed design. At this point in time, knowing how any possible reliability design weaknesses are to be overcome is of interest. This is the proposer's opportunity to detail and discuss the compensating features that are to be utilized. As an example, the state-of-the-art may indicate that redundancy of functions may have to be used in order to meet the estimated reliability.

The maximum environmental and stress conditions to which the system may be subjected during its various life phases must be estimated. The proposer is required to identify the anticipated problem areas relative to the capability of the components, equipments, subsystems, etc., to withstand the estimated environmental or stress conditions and manufacturing limitations.

Whenever Government Furnished Equipment or sub-contractors' equipment is to be integrated into the system, the proposer must show the compatibility of this equipment with the desired reliability requirement. The proposer will identify the reliability problems which have been introduced by equipment over which the contractor has no control; for example, Government Furnished Equipment. The proposer must indicate the degree of improvement necessary to make this equipment consonant with the rest of the equipment comprising the total system or subsystem.

Finally, the "first prediction" will acknowledge as well as identify the proposed preventive maintenance cycle that will be required to maintain the orders and levels of reliability that are being predicted. This should include the type of maintenance, as well as the duration of the maintenance cycle. Discussion must clearly identify the extent and degree of preventive maintenance that will be required.

Design Reviews

Participation in the review and evaluation of all equipment and component design is considered one of the most important activities of a contractor's reliability department. The technical proposal is expected to clearly indicate the specific procedures that will assure that all design and engineering changes occurring during the entire cycle (development through final fabrication) will be subject to effective reliability-design reviews. Further, the reviews for reliability must not be of an "advisory" nature. The reliability department must be in a position to detect and eliminate potential causes of low reliability and/or low maintainability early enough in the program to re-design when re-designs are the least costly. However, it is the design engineer's responsibility to effect the actual re-design. The cost involved in changes during the initial design is estimated to be 1/1000th that of the cost after equipment has been fabricated and delivered to the military user in the field. Figure 2 is a graphical illustration of this point, that it costs approximately 1000 times more for re-designs to delivered equipment than it would be to have made that same change in the Initial Design Phase. Figure 2 was developed by the Air Force Logistic Command and was detailed in a paper by Lt Col Samuel H. Lewis, Wright-Patterson AFB, "Customer Requirements for Maintainability (M) Characteristics in Air Force Systems and Equipment." The ratios for the costs in the Production Phase and the Development Phase are also shown.

$1.00	Initial Design Phase	Development Phase	$10.00
$1000.00	In-Service Phase (Retrofit & Maint)	Production Phase	$100.00

Figure 2. Initial Design Costs vs Re-Design Costs

Equipment Reliability Demonstration

The contractual requirement of a minimum mean-time-between-failure (MTBF) for an equipment introduces the problem of reliability demonstration. Electronic systems usually are operating with at least four constraints:

a. Equipment MTBF's are in the order of 500 hours or more.
b. Limited numbers (usually one or two) of articles are purchased.
c. Delivery schedules are compressed.
d. A finite number of dollars are available.

With such constraints, the present reliability demonstration model defined in USAF Specification MIL-R-26474 requires supplemental instructions to assure a satisfactory solution to the demonstration problem. The object is to insure that no suspended decisions will be necessary on compliance to contractual MTBF's. These can last as much as a year (many electronic equipment programs require delivery within eight to ten months from contract award). A quantitive decision rule or model is required which has at least the following essential properties:

a. It is understood by both the customer and contractor.

b. Quantifies the risks involved in decisions, i.e., the probability of rejecting equipments which have achieved the contractual MTBF and the probability of accepting equipments which have not achieved the contractual MTBF.

c. Allows scheduling and cost analysis within the overall constraints of the program.

A simple decision rule is being used which satisfies the above essential properties. This rule states that equipment will be planned to be operated for a specific amount of time (such as one multiple of contractual MTBF) and during this time a specific number of failures will be allowed. If this number is exceeded, the equipment will be declared unacceptable.

For example, assume the case where test time is set equal to θ_c, the contractual MTBF. If c is set equal to zero, a contractor would have a 39% chance that, even if his equipment has an MTBF equal to $2\theta_c$, the equipment would be rejected. On the other hand, the customer has a 14% chance of accepting an equipment which has an MTBF equal to $1/2\theta_c$.

However, to minimize the contractors' risk, c could be set equal to one. If the equipment had an MTBF equal to $1\theta_c$, the contractors' risk (probability of rejection) would now be 8%, but then the customer would have a 42% chance of accepting an equipment which has an MTBF equal to $1/2\ \theta_c$.

This basic arithmetic illustrates the need for clearly defining and obtaining agreement on a value of c. It is important that some discussion on this matter take place; initially in technical proposals and later in contract negotiations. The point of consideration in these discussions is to make both parties aware of each others risks.

A reliability demonstration can be through equipment testing or through analytical or mathematical demonstration coupled with monthly reports. It is recognized that the basic sequential model presented in Specification MIL-R-26474 requires additional guidance for application to a complete electronic system with several alternate modes and redundant replacements for various functional circuitry. The basic sequential model is viewed as a possible vehicle for reliability demonstrations of a simple series system, a particular mode of operation of a complex system, a subsystem of a system, etc.

It is necessary that in the discussion of equipment reliability demonstration plans the following be detailed and developed in the Technical Proposal:

a. Prepare a general plan for demonstration of the achieved reliability at a specified point in time, including estimated number of test articles, and confidence.

b. Develop trade-off curves showing number of test articles or cost versus confidence.

c. Detail how the testing for reliability at the system, subsystem, equipment or component level, separately or in combination, will be performed.

d. State conditions and ground rules for deciding if a test shall be classified as a success or failure, or shall be excluded because of invalid test data.

e. Indicate the scope of the detailed plans for conducting a reliability demonstration. The contractor must submit these plans to the customer at least ten days prior to the date the design review begins.

f. Detail the corrective action procedures that will guarantee that data collection results and design reviews are effective.

A reliability test plan is not considered complete until a clear indication of the contractor's failure feedback system and corrective loop is presented.

Failure Data Collection

Failure rates and the underlying mathematical model are utilized for the important area of spares provisioning. Current costs of spare parts for Air Force electronic equipments and systems average 15% to 20% of the total contract. Considering the total costs of some elec-

tronic systems, spare parts alone for a large electronic system can readily cost millions of dollars. Inadequate Failure Data procedures can mean a difference in millions of dollars both to the military services and to the taxpayers by excessive spares purchases. Further, it is possible to increase down time by improper spares provisioning and thus create other types of costs due to shortage of spare parts.

The prospective contractor must demonstrate that he understands the relationships, the interplay, and the interdependency between Failure Data Collection, the spares provisioning process, the maintenance aspects, as well as the improvement in reliability that can be derived by establishing and effecting the proper Failure Data Collection System.

Specification MIL-R-27542A defines "failure," however, further information for application to electronic system Technical Proposal Evaluations is usually supplied. It is important that "failure" be defined by the contractor, specifically and explicitly for the particular equipment or system under procurement and as the contractor intends to apply it to the Reliability Program. Failure in one circumstance can be a simple breakdown of a component such as a receiver or transmitter. Failure may also be defined as the inability to communicate between two geographical locations. Failure, therefore, can be through equipment or be operational or even a combination of the two. Failure of a single component can be catastrophic when the component is the only one of its type, or is one in a chain of components. On the other hand, a failure of one of the sequential parallel transmitters in the phased array radar could not be considered as catastrophic because only a small decrease in performance would result. Failure of indicator lamps, test points, alarm circuitry, etc., which do not affect system performance, are not normally included in the MTBF calculations. The technical proposal should therefore indicate an understanding of, and the proper application of the proposed Failure Data Collection System, and should define the various categories of failure as they are used in the contractor technical proposal.

Organization for Reliability

There are many ways of organizing to achieve reliability. It is not the intent here to describe the ideal or preferred organization. The bidder must develop and describe an organization that meets the requirements of a particular program. A Reliability Group, for example, does not have to be a permanent organizational group; it is satisfactory in certain instances to have only a permanent Chairman, with members available as required. The following aspects are considered particularly important:

a. Qualified Personnel: It is necessary for the prospective contractor to identify, by professional skills, the personnel to be assigned to the reliability program. An assessment will then be made by the technical evaluators whether the number (particularly those to be assigned full time) is adequate, considering the scope of the proposed overall program. Previous experience of the personnel in reliability

design, reliability prediction and reliability management group as a whole, in the areas of analysis, design, statistical methods, parts and test methods, are to be detailed, and are of particular interest.

The end product under procurement to a large degree, dictates the type of reliability personnel to be assigned to a particular contract. In some programs personnel with general reliability engineering backgrounds are more important. If extensive reliability mathematical models are used, mathematicians and analysts are a must, and a lack of these skills might be interpreted as a lack of understanding of the reliability problems involved.

b. Reliability Organization: The contractor's organizational framework is of interest and more specifically, the structural position of reliability activities in relation to engineering, manufacturing, and quality assurance. It is understood that not everyone can or even should report directly to the president of the corporation, but the reliability organization should be in a position to participate in the formulation of design criteria and to effectively control the design of the end item for reliability. It is particularly important that the Reliability Group not be submerged, in manufacturing for example.

c. Effectiveness of Reliability Organization: It is necessary that the technical proposal demonstrate that the prospective contractor's Reliability Group will be truly responsive to overall end item requirements, sensitive to design problem areas that evolve anywhere in the company, and that organizationally the work of the reliability group is timely. In other words, does the Reliability Group have stature and authority? Is there a positive management means for auditing the progress of the reliability activities? Is there an effective means for crosstalk and feedback of information between the reliability, the engineering, manufacturing, test and quality control activities? Conversely, the Reliability Group should not have an overriding authority to re-design equipment or circuits, just for the sake of reliability; rather, the contractor's Design Review Teams should consist of an active, voting Reliability representative, who will participate in all design reviews, and whose considered reliability opinions will be pertinent.

d. Utilization of Consultants and Advisors: Listing advisors and consultants on an "as required" availability basis is a very common practice among bidders today. The individuals listed are generally nationally recognized specialists or authorities in their particular fields. Five, ten, or even twenty percent of their time may be promised to the contract, but frequently the individuals appear on the roster only for prestige purposes. Past experience has shown that all too often these "big names" are not assigned to the program or spend insufficient time to be of tangible benefit to the program. The Technical Proposal must indicate the specific functional responsibilities or areas to which the consultants and advisors will be assigned, and the specific contributions that they will be expected to make to the total program.

Another practice common today shows Vice Presidents, Department Managers, or even Presidents, as overall project leaders. Again, the technical proposals must carefully specify the precise function that executives will perform, since it is known that in practice, it is

primarily the full-time project personnel that can be depended upon for the day-to-day continuity required to bring any reliability program to a successful completion. Vice Presidents and Chief Engineers can rarely devote sufficient time to project engineering without sacrificing their demanding and time-consuming executive responsibilities.

Consultants and advisors have made valuable contributions to many defense contracts. Their participation is encouraged, if there is a genuine need for their talents and experience, and provided that a consultant's commitment of time is made in writing, and is submitted as part of the Technical Proposal package.

Reliability Incentives/Penalties

A number of recent ground electronic system contracts have had the reliability effort priced separately. This has caused increased attention to the reliability aspects, however, this has also led to additional Air Force controls over that portion of the contract costs. One of the resultant controls is the Reliability Incentives and Reliability Penalties.

The Air Force and the Department of Defense have expressed a growing concern about inadequte contractual provisions for the assurance of system/equipment reliability. As a result, Cost Plus Fixed Fee (CPFF) contracts are being used on a highly selected basis only, and are being replaced by incentive fee type of contracts. Contracts with established incentive fees have been expressed quantitatively in mean-time-between-failures (MTBF) and a reliability program tailored to the general requirements of MIL-R-27542 has been established. The primary objective of the incentive fee is to preclude, or at least minimize, the various uncontrollable factors which arise during the course of a contract, and result in failure to meet the reliability requirements.

The inclusion of reliability incentive fees is intended to insure that contractor-allocated funds for the contractor's reliability program will not be redirected to some other contract activity, particularly when the contractor is experiencing some difficulty with other facets of the contract. Much of the DOD guidance on Incentive Fee Contracts applies directly to the reliability portions, and is particularly applicable to electronic systems.

Experience with electronic systems has indicated that the system hardware evolved during the R&D effort usually becomes the system that is delivered and installed as an operational system. This, therefore, dictates that the initial design must be the right one, since there is no second chance to significantly increase low or unsatisfactory orders of reliability. The DOD Guide on Incentive Fees states that "a contractor should be motivated, in calculable monetary terms to:

a. Turn out a product that meets significantly advanced performance goals.

b. To improve on the contract schedule up to and including

final delivery.

c. To substantially reduce the costs of the work, or,

d. To complete the project under a weighted combination of some or all of these objectives"

The DOD instructions are quick to caution, however, that the performance incentive (including reliability) will not be used under any circumstance, as a substitute for a clear definition of the desired end item. It is intended that the performance incentive emerges, not as a means of turning the program into a profit "game" operating between very wide limits, but simply as an inducement to the contractor to meet or exceed the nominal performance requirements as established in the contract.

In a recent electronic communications system contract award, the following provisions regarding reliability were instituted:

a. The contract is a cost-plus-incentive fee (CPIF) type, with performance, cost, and the delivery as incentive features.

b. The overall incentive arrangements are weighed as follows: Performance - 60%, Delivery - 10%, Cost - 30%.

c. Under the Performance weights, Reliability is weighed at 24%, and is based on the amount by which the minimum specified reliability and confidence, as stated in the Statement of Work, are exceeded by completion of ground testing.

Figure 3 pictorially depicts a progressive relationship for reliability incentives and penalties. The precise nature and the percent effect on the fee can vary considerably depending on the nature and operational use of the equipment being procured. The exact fees are determined during pre-contractual negotiations. Bidders are, however, encouraged to respond or to suggest alternate incentive/penalties arrangements. There is Air Force interest in varying arrangements in order that sufficient experience may be gained and eventually, realistic relationships established that will not unduly penalize either the military customer or the industrial concern developing new electronic systems.

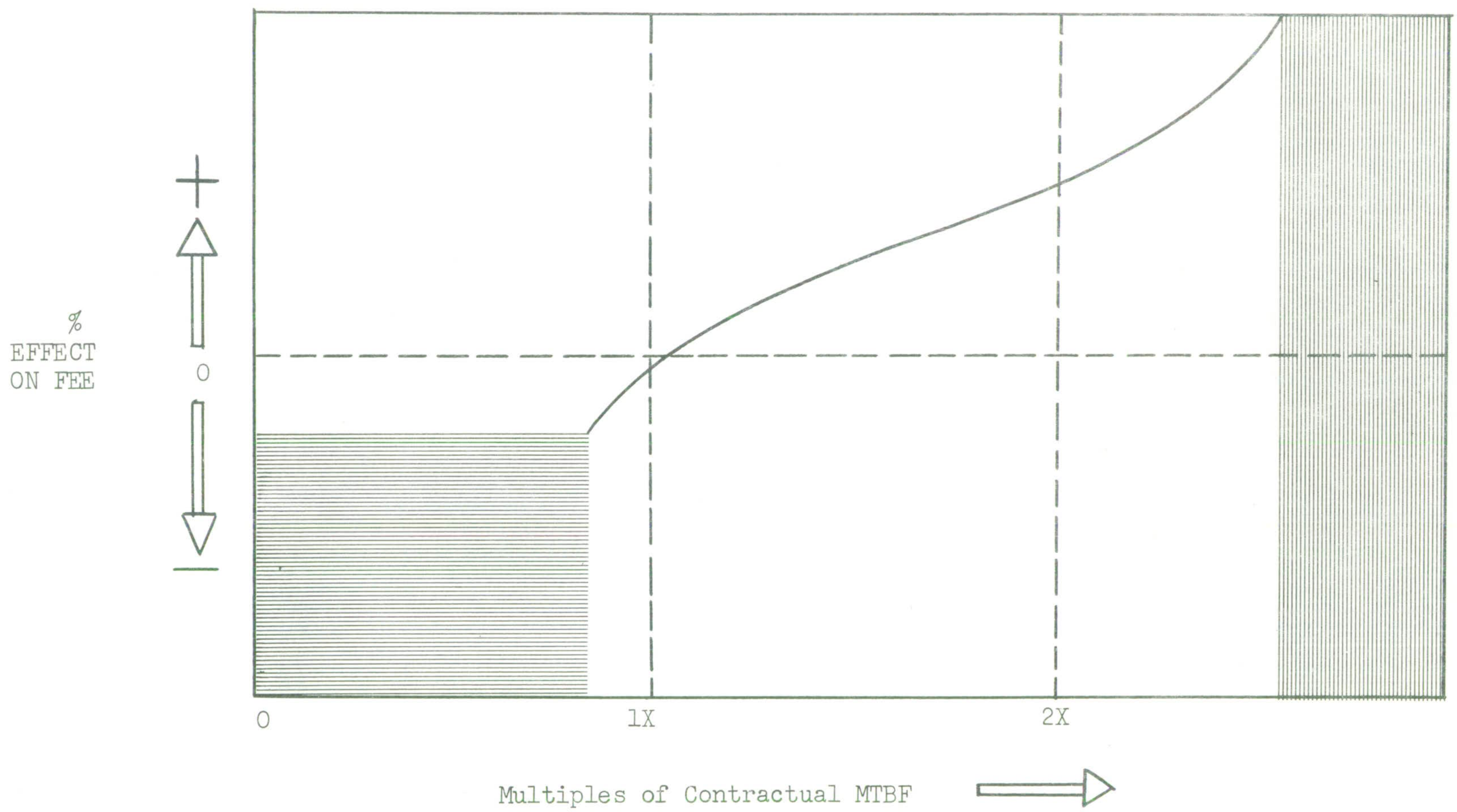

Figure 3. Progressive Relationship for Reliability Incentives/Penalties

SECTION IV

RELIABILITY ECONOMICS FACTORS

Technical progress in the state-of-the-art for reliability has always been an important factor in technical proposal evaluations. Experience with many contracts demonstrated that the following aspects of reliability are equally important.

Effect of Reliability Upon Maintenance Costs

Requirements for high reliability invariably result in increased contract costs. The Air Force is interested in total costs, not just the initial purchase price of the equipment. Reliability has a dramatic impact upon spares, manuals, test equipment, checkout devices, calibration, and all logistic actions. Technical proposals should not justify reliability costs on increased performance alone. Reliability costs should specify the impact and the potential savings in the area of maintenance.

Mr. E. J. Nucci (DDR&E) in the September 1963 IEEE Transactions on Reliability paper, titled "Concepts and Research Needs of Reliability in Military Systems," released the following information:

a. Current DOD maintenance budget is more than $10,000,000,000 per year.

b. 960,000 military and civilian personnel utilized for maintenance alone.

c. Contractor maintenance of military equipment will decrease.

d. Military maintenance costs are expected to increase.

Ten billion dollars per year is approximately 20% of the National Defense Budget. Prorated, this is more than 1,000,000 tax dollars for each and every hour of the year, just for the maintenance costs. Predicted reliability has become one of the important tools used by evaluators to assess the overall cost including operation and maintenance.

Technical proposals should use various approaches to indicate the potential contractor's concern with the military maintenance problem. Figure 4 shows the effect of component parts failures on the ultimate logistic costs. The percentage of failures is directly proportional to replacement costs. The average unit replacement cost of $20 per failure was developed as the result of a study by the RCA Service Co. for the Rome Air Development Center, and was detailed in a paper by Messrs R. L. McLaughline and H. D. Voegtlen, "Ground Electronic Equipment Support Cost vs Reliability and Maintainability." The costs include material, manpower, transportation and administrative costs, but exclude such additional costs as loss of product, storage facilities, depots, pipe lines, spare parts stockage, etc. The effect of selection of parts, in

percentage failure per 1000 hours, has been charted for a high density ground electronic system. The direct relationship between failures and replacement costs is shown. Using the basic cost factor of $20., the table of costs is based upon the four failure rates listed as basic requirements by the "Darnell Report" Parts Specification Management for Reliability (PSMR).

% failure per 1000 hours	Nr. of failures per 1000 hours for 1/2 billion part density system	Average Cost for Unit Replacement	Cost per 1000 hours	Cost for 50,000 hours
1.0	5,000,000	$20.00	$100,000,000	$5,000,000,000
0.1	500,000	20.00	10,000,000	500,000,000
0.01	50,000	20.00	1,000,000	50,000,000
0.001	5,000	20.00	100,000	5,000,000

FIGURE 4

From the elementary figure in Figure 4, it can be readily seen how much can be saved over a period of 50,000 hours (the normal life of ground electronic equipment) by selecting the next highest reliability level of parts. Taking as an example the reliability levels of 0.01% - 0.001% failures per thousand hours, a saving of 45,000,000 is accrued over the 50,000 hour period by choosing the o.ool% failures per thousand hours of operation. These savings applied during the design and development phases would result in many other savings, in addition to any improved end product. These additional savings would include such items as reduction in manpower and training requirements, less redundancy, fewer number of items in the logistics supply lines, less transportation and administrative costs, less storage facilities, and less depot support requirements. Although these figures are approximate and cover a small area of the economy of reliability, it is readily apparent that many benefits and economies may be achieved through design for reliability. Bidders are encouraged to use similar approaches, particularly when it is the considered opinion of the prospective contractor that it is feasible within the state-of-the-art to exceed the reliability requirements being specified in the Request for Proposal.

Reliability as a Cost Factor

AFR 80-5, "Reliability Program for Systems, Subsystems, and Equipment," states "Proposals for increasing reliability efforts on programs in existence will be considered on the basis of the net effect on the overall Air Force capability and economy, including such factors as spare parts requirements, maintenance workloads, engineering changes, operating costs, and the effect on the system concerned." Figure 5 illustrates this point, and shows the relationship between the reliability of complex electronic systems and total systems cost. Figure 5

is an adaption of the AGREE Mission Cost vs Reliability model. As the design-for-reliability is emphasized, a proportional reduction in the Support Costs is reflected. There is, however, an optimum point beyond which additional design effort on reliability may not be warranted. At this optimum point, the design-for-maintenance becomes an important contributor.

Figure 5, page 24, indicates how an initial expenditure in time and funds, to improve current reliability levels (shaded area), will reduce total costs. The curves are typical of those that could be developed by bidders and used to establish reliability requirements defining a system of maximum value to the customer.

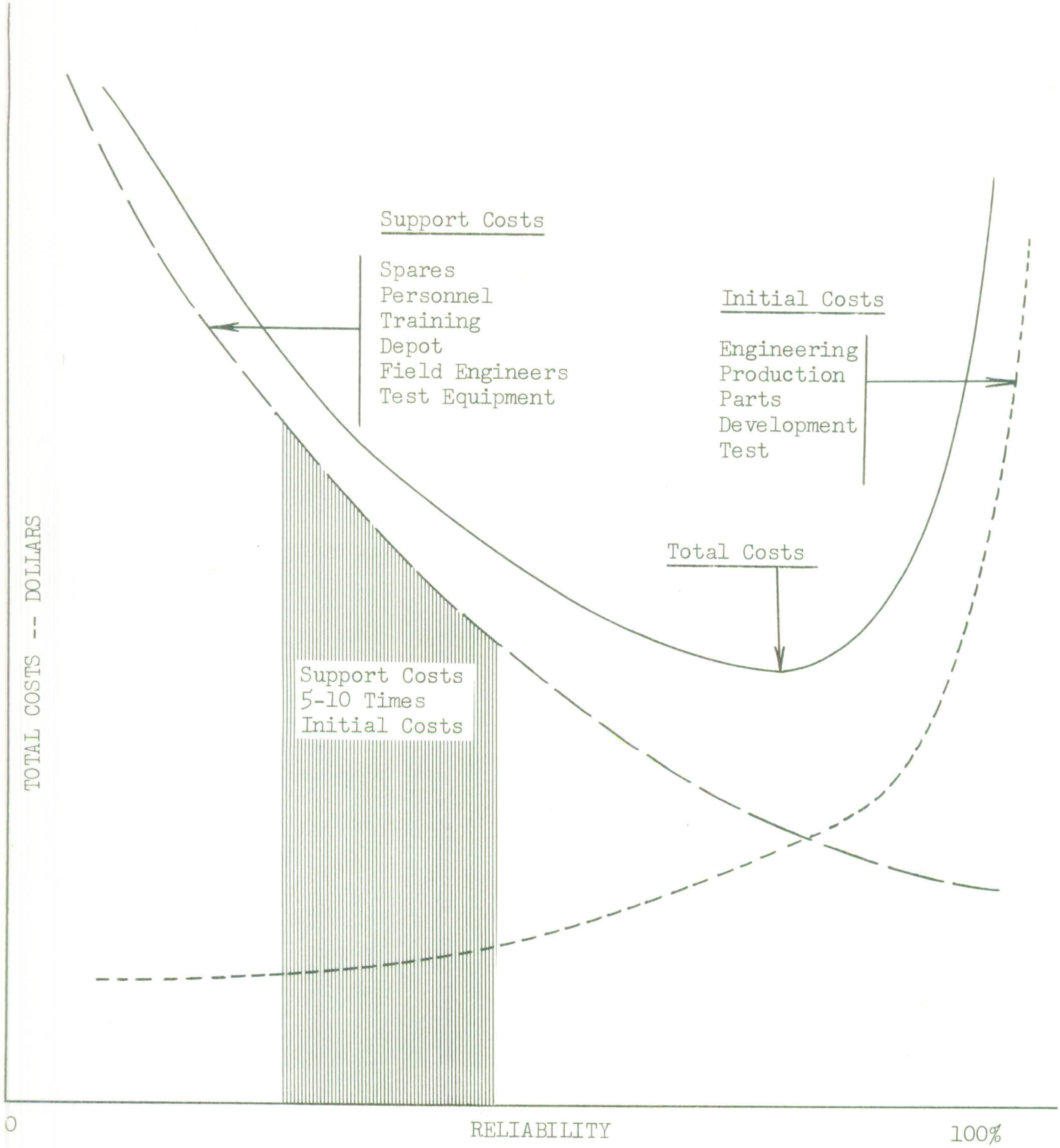

Figure 5. Relationship Between Reliability and Costs

SECTION V

APPROACHES FOR INCREASED RELIABILITY

Basic Reliability Approach

The reliability of electronic equipment largely depends upon the following fundamental factors:

a. The inherent design of the circuitry and the technique of packaging of the hardware.

b. The reliability of the components and materials used.

c. The workmanship, assembly, and control techniques during manufacture.

d. The operational use and application of the equipment.

e. The maintenance techniques used after installation of equipment in its operational status.

Past experience suggests that there is another facet which affects reliability; as the complexity of the equipment is substantially increased, the reliability levels depend primarily on complexity. As complexity increases, the reliability level decreases.

Figure 6 is a chart developed by the Rome Air Development Center which describes RADC's experience with ground radar equipments. Figure 6 shows historically and statistically that as the number of active elements increased, the reliability-probability of operating for a 24 hour period decreased. At this point in time, reliability in MTBF appears to have leveled off, but Air Force radar sets are becoming more complex.

However, this is true only for series type functions. In actual practice, one ground electronic system has been made deliberately complex to achieve the necessary reliability.

Increased Reliability Through Redundancy

Ground electronic equipment traditionally has rarely had the physical space limitations that are inherent in aeronautical, missile or space systems. Generally, ground electronic equipment has had literally acres of land on which the equipment could be installed. Physical weight has only occasionally been a primary consideration. Power sources were also a secondary consideration, and never a serious limitation, because a few additional kilowatts of power could always be secured by introducing additional or increased capacity motor generators, etc. The result has been ground electronic equipment that is generally and permissably bulky, heavy, and consumes sizeable quantities of power. Additionally the maintenance and transportability aspects are increased.

As ground electronic equipment grew more complex, designers

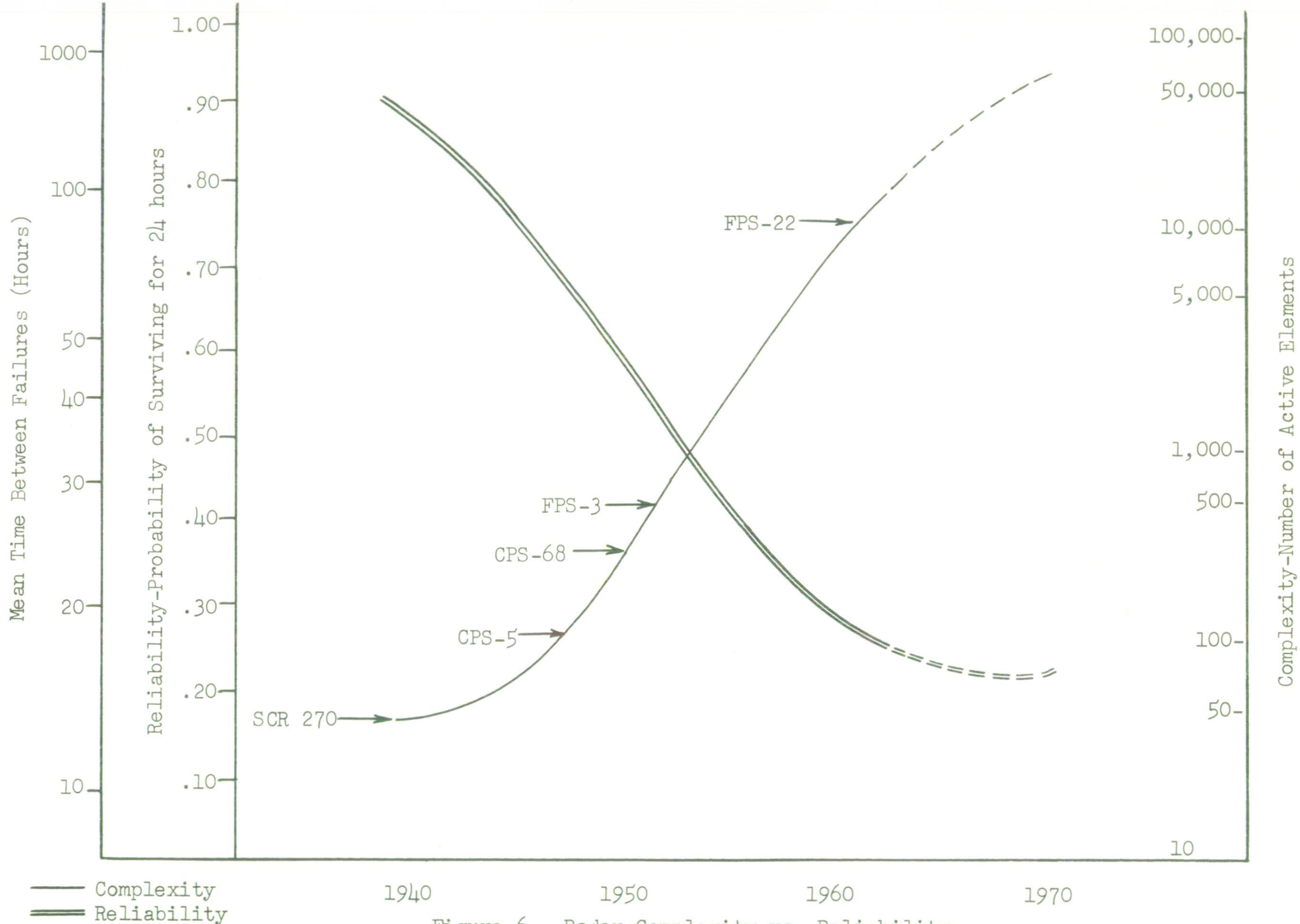

Figure 6. Radar Complexity vs. Reliability
(Not including redundancy)

used a common technique, equipment redundancy, to gain increased reliability. For example, large scale computers were duplicated to insure reliability and operational availability. Radar klystrons were paralleled to provide switch-over to the stand-by unit in the event of failure. In some cases, complete receivers and transmitters are maintained in stand-by readiness, to permit and assure reliability/availability. All these techniques were permitted with the reluctant approval of the Air Force, for expediency and lack of other approaches. The result, however, has been an inordinate and astronomical increase in the support, logistics and maintenance aspects. More than 30 percent of the Air Force budget is for maintenance of today's systems, and that maintenance of electronic equipment ranges between sixty and one thousand times the initial costs. Redundancy techniques of the type described are therefore no longer encouraged.

Reliability Through Increased Complexity.

One redundancy technique which has been generally accepted is that used by Phased Array Radars. The basic concept in Phased Array permits the use of low power, identical transmitters by the introduction of phase shift to result in an electronically steerable high-power antenna. Basically, phased array, as used in ground electronics, consists of some 5000 identical low-power transmitters and is essentially a case of "natural redundancy".

Phased Array virtually eliminates major failures in radar receivers and radar transmitters. Additionally, the failures associated with the antenna dish, the antenna feeds, the pedestals and the servos are almost eliminated. It is possible to have 10% of the 5000 transmitters defective and yet maintain negligible loss of power and efficiency. Basically, the "series" operation problem has been eliminated. Phased Array is discussed here to indicate that although brute-type redundancy is not generally favored, there are techniques such as Phased Array that are acceptable, and that have reached satisfactory levels of reliability, although parts complexity is extremely high.

Series-systems such as Telstar and Minuteman have been proven reliable; therefore, when prospective contractors use brute redundancy as the primary approach to the required operational reliability, the proposals will receive particularly close scrutiny. It is also possible that lower evaluation weights will be assigned to such proposals. Sophisticated redundancy approaches such as the Phased Array radar are encouraged and should be introduced during the Technical Proposal evaluation stage.

SECTION VI

CONCLUSION

The procuring agency should initially define the job to be undertaken in great enough detail so that the prospective contractor may understand what the Air Force wants. It then becomes the responsibility of the bidder to simply and clearly describe what he will deliver. It is not sufficient for the bidder to merely discuss or develop each of the reliability requirements listed or referred to in the Request for Proposal. It is necessary that the bidder develop, emphasize, and prove to the military customer that he, the contractor, will have a dynamic reliability program that will be tailor-made to a particular program. Further, reliability cannot be treated as a separate and peculiar science; it has an impact upon many other important areas, and it is important that the interactions and tradeoffs with maintainability, quality assurance, logistics and maintenance be fully developed in the Technical Proposals submitted.

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13. ABSTRACT

Reliability is a major design factor that must be considered in the initial system planning, during the design and development phase, and throughout the manufacture, site installation and checkout, and test cycle. Prospective contractors are required to clearly demonstrate in their proposals that the proposed configuration will meet the specified military reliability requirements. This paper discusses and details those factors which must be developed by prospective contractors to assure responsiveness to the reliability/quality aspects. Although the emphasis is on electronic systems and equipments, the basic precepts described are readily adaptable to all Air Force systems and equipments.

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